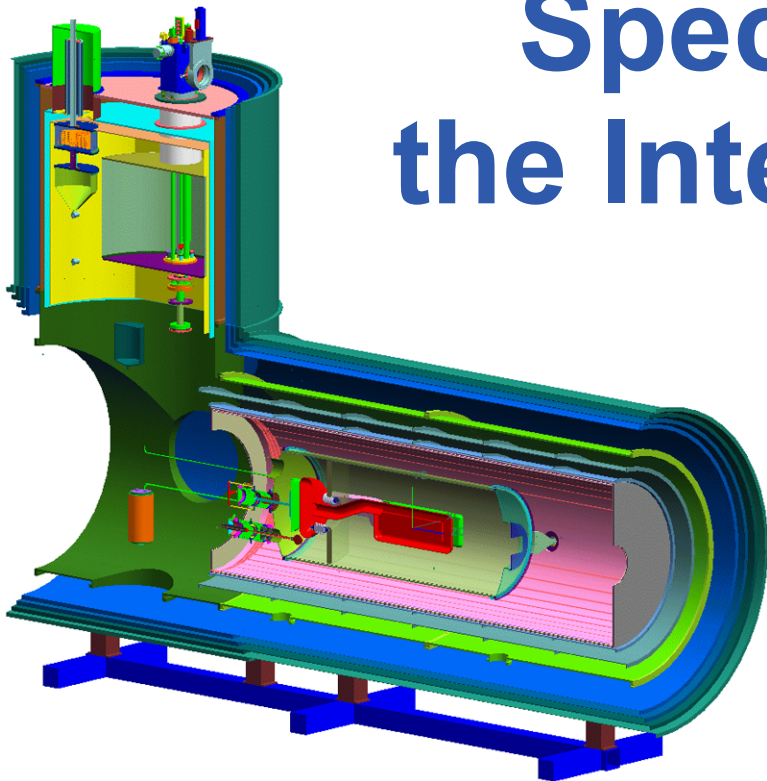




Specifications for the Integrated Tests III

Paul Huffman



Goals of this Discussion



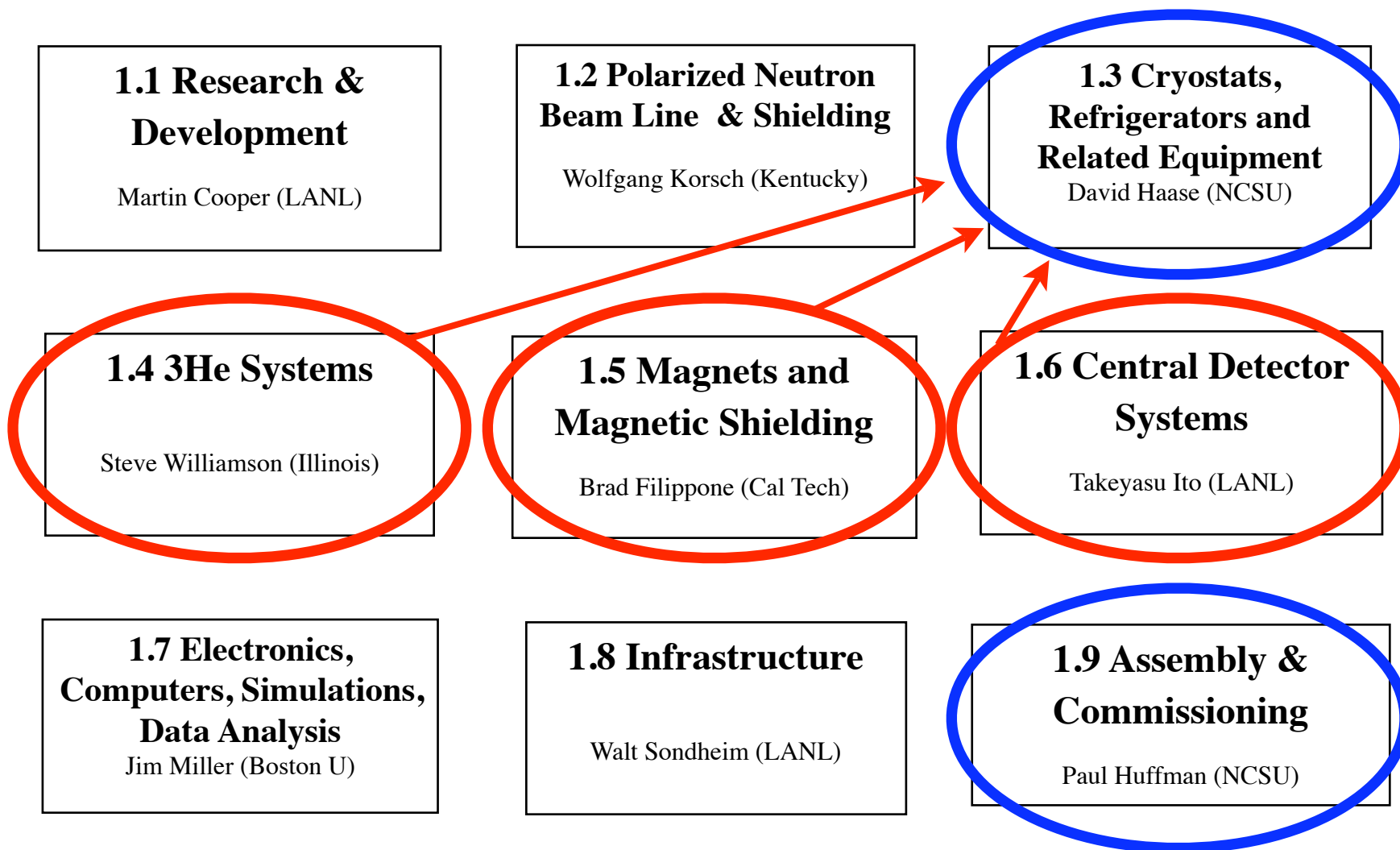
- DOE recommendation:
 - “Prior to CD-2, develop testing plans that identify the activities and goals for the performance tests of the subsystems at the individual institutions and the assembly site.”

- Insure we meet the CD-4 requirements
- Remind everyone again of what we have told DOE
- Round 2.14 of specifying some internal benchmarks that are more stringent than these DOE minimums

Overall Challenge



- To bring together the tested components from the individual work packages and integrate them to form a complete apparatus.



- To bring together the tested components from the individual work packages and integrate them to form a complete apparatus.
- Three individual subsystems must be integrated into the fourth subsystem (cryogenic vessel) before we can take data:
 - Measurement cell and high voltage system
 - Cryogenic magnetic shields and coils
 - ^3He polarizer, purifier, and transport system
- We estimate that each cooldown cycle will take approximately two months. This drives our schedule. We want to keep the number of cooldowns to a minimum!

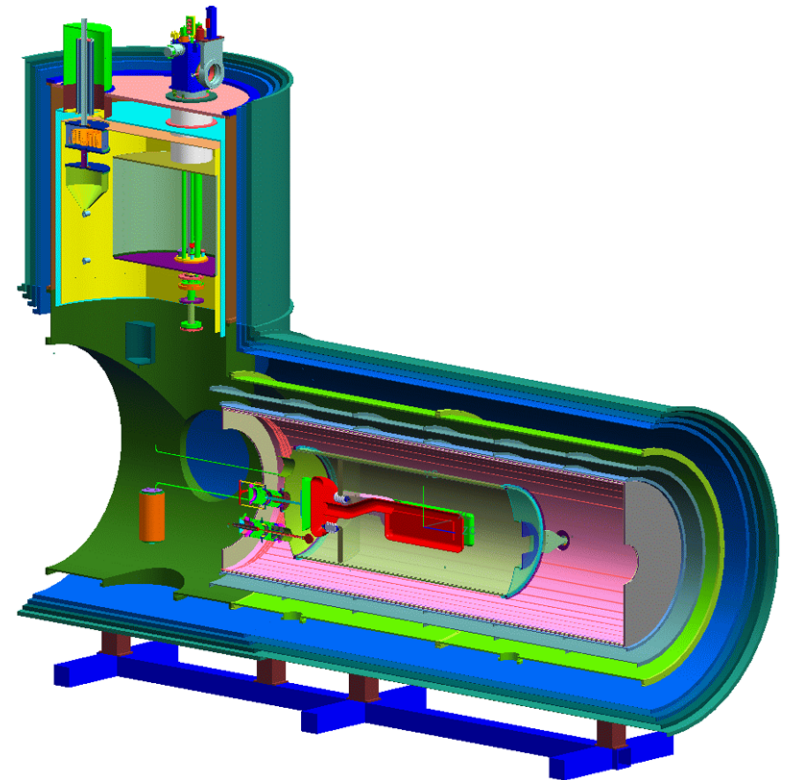
- The subsystems arrive at ORNL fully tested.
- The subsystems will be incorporated sequentially in the cryovessel.
 - Measurement cell and high voltage system
 - Cryogenic magnetic shields and coils
 - ^3He polarizer, purifier, and transport system
- We require the ability to integrate and test all subsystems w/o the external magnetic shield.
- Integration of the DAQ and other external subsystem components will occur in parallel as the systems are integrated. They are ignored in this talk.
- Dedicated cryogenic personnel will be hired by ORNL.

- Everything is dominated by the number of cooldown cycles required for successful commissioning. Our best guesses for the number of cooldowns are:
 - 3 - coil package
 - 4 - insert
 - 4 - ^3He components
 - 5 - integrated tests and commissioning (w/ beam, B-shield)
- Debugging of systems before they arrive is essential. Tests that could take one week in a smaller test apparatus will take at least two months in the main cryostat.

Major Systems as We Have Defined Them

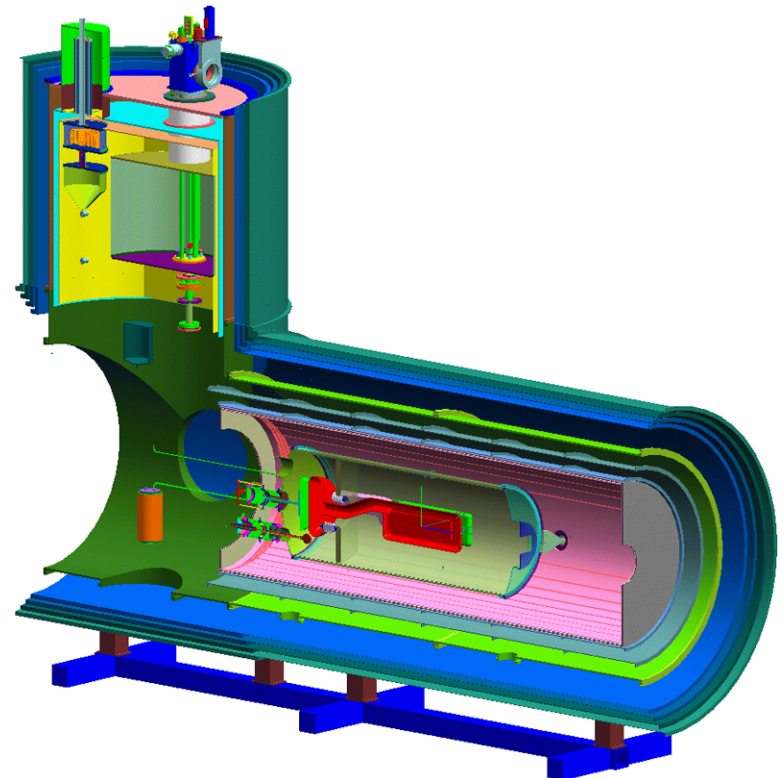


- Cryovessel
- High voltage system and detector insert
- Magnetic shields and coil package
- ^3He systems



0. Cryovessel

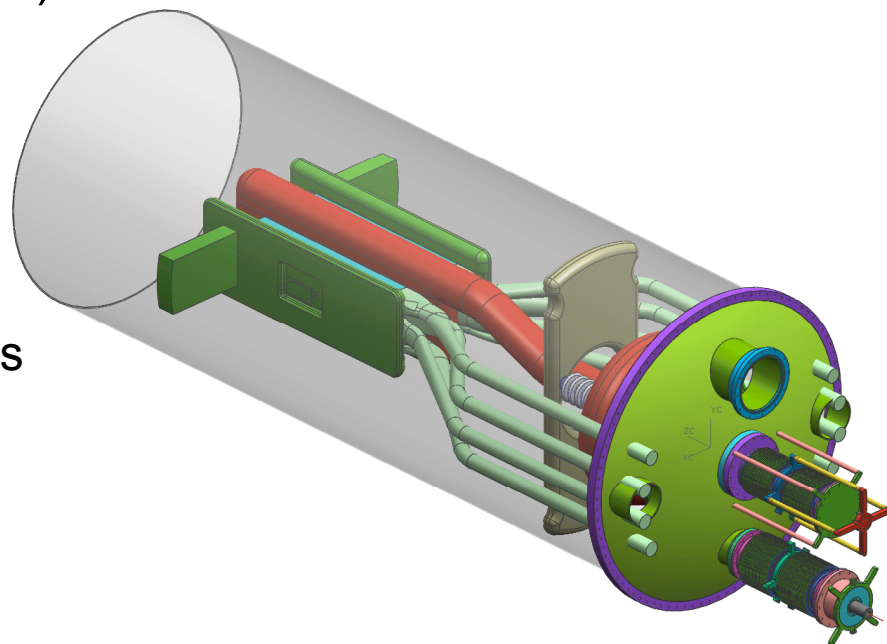
- Major components:
 - Helium liquefier and gas storage system
 - Liquid helium transfer system
 - 300 K outer vacuum can
 - 50 K temperature shield
 - 4 K temperature shield
 - 1200 l central volume
 - Dilution refrigerator(s)
 - Instrumentation and controls



1. High Voltage System and Measurement Cell



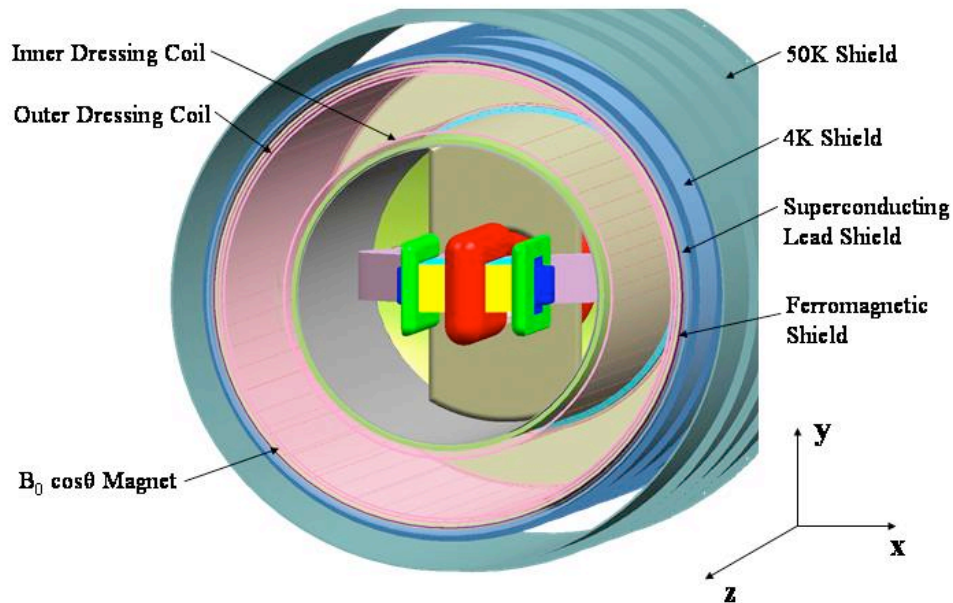
- Major components:
 - High voltage system ($T < 500$ mK)
 - capacitor plates
 - cell electrodes
 - high-voltage feedthroughs
 - power supplies
 - Detection system ($T < 500$ mK)
 - dTPB coated measurement cells
 - light collection optics
 - light guide feedthroughs
 - PMT's or equivalent



2. Cryogenic Shields and Coil Package



- Major components:
 - Coil package ($T = 4\text{K}$)
 - $\cos(\Theta)$ magnet
 - inner dressing coil
 - outer dressing coil
 - trim coils
 - coil support frames
 - Shielding package ($T = 4\text{K}$)
 - superconducting shield
 - ferromagnetic shield
 - ^3He coil package and shields ($T = 4\text{K}$)
 - Instrumentation for field monitoring

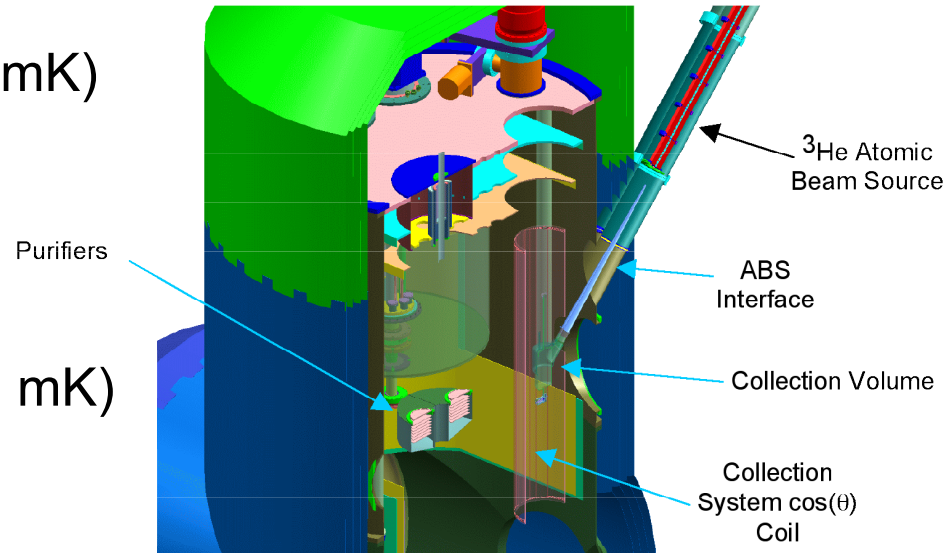


3. ^3He Injector and Purifier



■ Major components:

- atomic beam source ($T < 500 \text{ mK}$)
 - source itself
 - interface to the apparatus
 - ^3He collection volume
 - transport coils and shields *
- ^3He transport system ($T < 500 \text{ mK}$)
 - valves and tubing
 - expansion volumes
 - ^3He depolarization in cell
- ^3He purifier ($T < 500 \text{ mK}$)
 - charcoal pumps
 - volume displacement for level control
- Instrumentation and controls



* Cryogenic shields and coil package subsystem

- Cryogenic vessel
 - Demonstrated to cool the central detector volume to 500 mK
 - Operated with the magnet coil package in place
- Magnet coil package
 - $\langle dB/dx \rangle / B_0 < 10^{-5} / \text{cm}$ at 77 K *
- Four-layer magnetic shield
 - Shielding factor of 10^{-4} *

* Tests performed offsite



■ Central detector insert

- High voltage holds 5 kV/cm with a leakage current <10 nA
- Mean number of photoelectrons from 750 keV of energy deposition is ≥ 4
- SQUID noise $<100 \mu\Phi_0/\sqrt{\text{Hz}}$ in 10 Hz bandwidth that, based on independent tests, implies a $S/N > 1$
- Neutron storage time in similar cell demonstrated to be >100 sec in an independent test

■ ^3He services

- Produces $\geq 10^{11}/\text{cm}^3$ of $\geq 70\%$ -polarized ^3He in the collection volume as seen with a SQUID*
- Purifier reduces the ^3He concentration to less than 1 part in 10^{11} *
- ^3He demonstrated to move between volumes with a time constant of 500 s or less*
- Valves shown to operate over 500 cycles*
- Installed in the cryogenic vessel

■ Neutron guides

- Flux out/MW $\geq 4 \times 10^5 \text{ n}/\text{\AA}/\text{cm}^2/\text{s}/\text{MW}$ @ 8.9 \AA with a polarization $\geq 70\%$

Table II-2. The Principle Specifications for the nEDM Experiment^a

Description	Minimal Performance	Optimal Performance
Operating Temperature (mK)	300–550	300–550
UCN Wall Loss Time (s)	200	2000
Capture Signal/Electron Background	0.5	50
³ He-Spin Relaxation Time (s)	200	30,000
³ He Polarization (%)	80	99
SQUID Noise ($\mu\phi_0$)/ \sqrt{Hz}	20	1
Magnetic Field (B_0) Uniformity	2×10^{-3}	5×10^{-4}
Magnetic Gradient $\langle \delta B_x / \delta x \rangle_{vol}$ ($\mu G/cm$)	0.05	0.01
Electric Field (kV/cm)	25	50
UCN Production Rate (/cm ³ /s)	0.08	0.3

^a The minimal performance is the first goal of the collaboration and the optimal performance is needed to reach the ultimate sensitivity.

Supporting Specifications

The supporting specifications are shown in Table II-3. The columns have the same definitions as for the principal specifications.

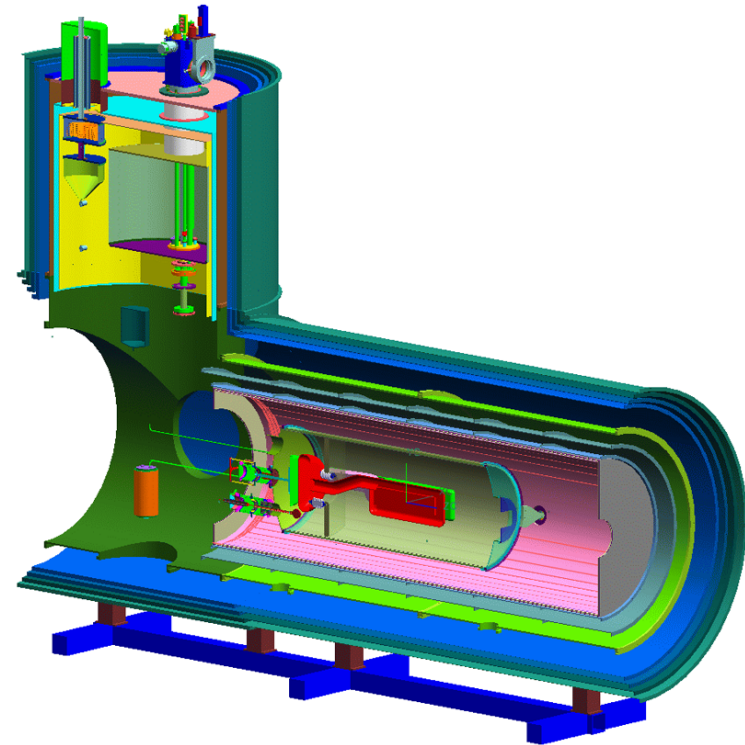
Table II-3. The Supporting Specifications for the nEDM Experiment.

Description	Minimal Performance	Optimal Performance
Total Experiment Live Time (yr)	0.3	1
Total Cooling Power at 450 mK (mW)	25	50
Cool Down Time (d)	28	14
Polarized ^3He Loading Time (s)	1000	100
Injection ^3He Polarization (%)	90	99.5
Maximum ^4He Purity (10^{10} atoms/cm 3)	10	1
Valve Lifetime (cycles)	5000	10^5
Mean Number of Photoelectrons/Event	12	40
Particle Identification Rejection	1	50
Magnetic Shielding Factor	10^4	10^5
Eddy Current Heating at 4 K (mW)	1000	100
Uniformities of Other Magnetic Fields	5×10^{-3}	10^{-3}
Coil Power Supply Ripple	10^{-6}	10^{-7}
Coil Winding Precision (mm)	5	1
Alignment of E and B Fields (deg)	3	0.5
Electric Field Spark Rate (/yr)	0.5	0.1
Electric Field Uniformity	10^{-2}	10^{-3}
Personnel Radiation Field (mR/hr)	0.2	0.2

Cryovessel (starting point)



- Demonstrated to cool the central detector volume to a temperature of < 250 mK at ORNL with the central volume full of helium.
 - Liquefier installed and operational
 - Dilution refrigerator(s) (DR) installed and has >80 mW of cooling power at 500 mK (heat applied to the cell)
 - Heat loads to DR/shields characterized and under control
 - Central composite helium volume installed and leak free (blank flanges)
 - Dewar vacuum tight with appropriate temperature shields
 - Fully implemented with diagnostic sensors

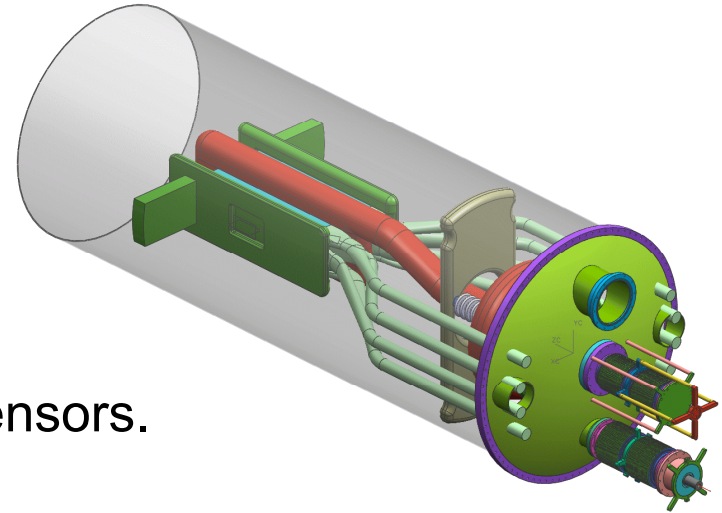


High Voltage System and Measurement Cell



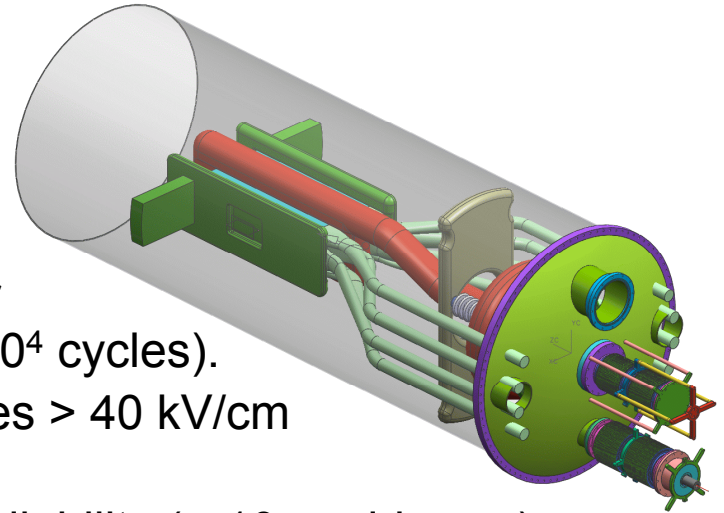
- Before arrival:

- Design fully incorporated into the cryovessel design and vetted from a cryogenics standpoint (ie. it will fit in and cool down). Assembly implemented with the appropriate sensors.
- Assembly shown to meet the CD-4 requirements at 0.5 K:
 - High voltage system shown to hold 5 KV/cm with a leakage current of <10 nA, with the cell and lightguides in place
 - The mean number of photoelectrons from 750 keV of energy deposition is > 4 , tested using a radioactive source placed in each cell while the cell is full of helium.



■ Before arrival (cont.):

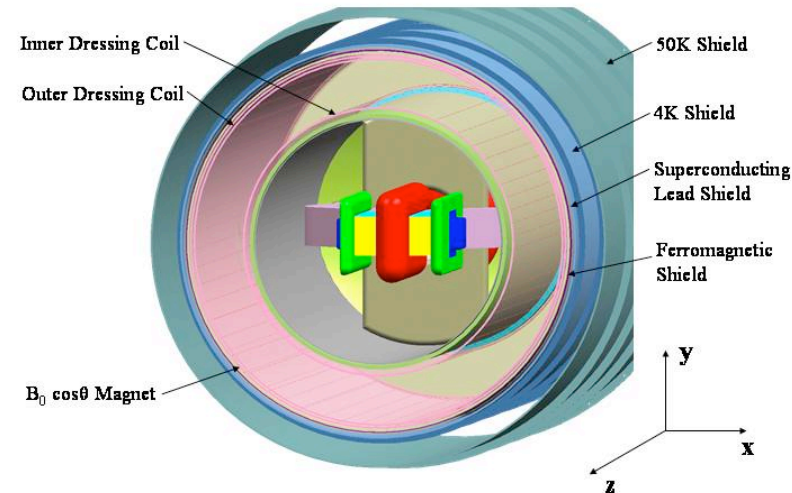
- Assembly shown to meet our collaboration requirements at 0.5 K:
 - High voltage feedthroughs tested for reliability at low temperature ($> 5 \times 10^4$ cycles).
 - High voltage system reliably produces > 40 kV/cm at 500 mK.
 - Light guide penetrations tested for reliability (> 10 cooldowns).
 - The mean number of photoelectrons from 750 keV of energy deposition is > 30 , tested using a radioactive source placed in each cell while the cell is full of helium.
 - High-voltage and lightguide feedthroughs shown to impart a total heat load of less than 20 mW into the central volume at 400 mK.
 - UCN storage time in cell measured to be > 1500 s
 - *Measured electric field spark rate* < 0.2 /year
 - Electric field uniformity measured to be $< 8 \times 10^{-3}$ over the volume of each cell.
 - Eddy current heating measured using RF coil to be < 5 mW



Cryogenic Shields and Coil Package



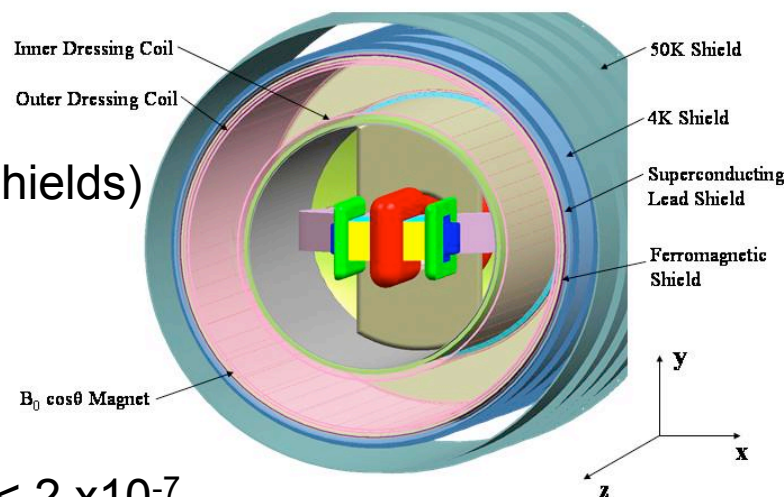
- Before arrival:
 - Design fully incorporated into the cryovessel design and vetted from a cryogenics standpoint (ie. it will fit in and cool down). System is implemented with appropriate sensors.
 - Assembly shown to meet the CD-4 gradient requirement at 77 K and high field:
 - $\langle dB/dx \rangle / B_0 < 10^{-5}/\text{cm}$



■ Before arrival (cont.):

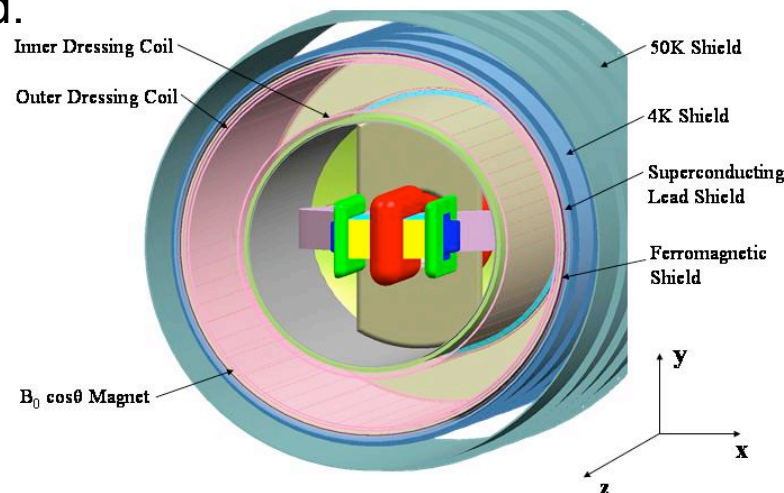
- Coil assembly shown to meet our collaboration requirements:

- High field uniformity test at 300 K performed (horizontally and vertically)
- High field uniformity test at 77 K performed (vertically)
- Low field uniformity test at 300 K performed (horizontally in magnetic shields)
- $\langle dB/dx \rangle < 0.05 \text{ uG/cm}$
- B_0 uniformity $< 2 \times 10^{-3}$
- Uniformity of other fields $< 2 \times 10^{-3}$
- Power supply ripple measured to be $< 2 \times 10^{-7}$



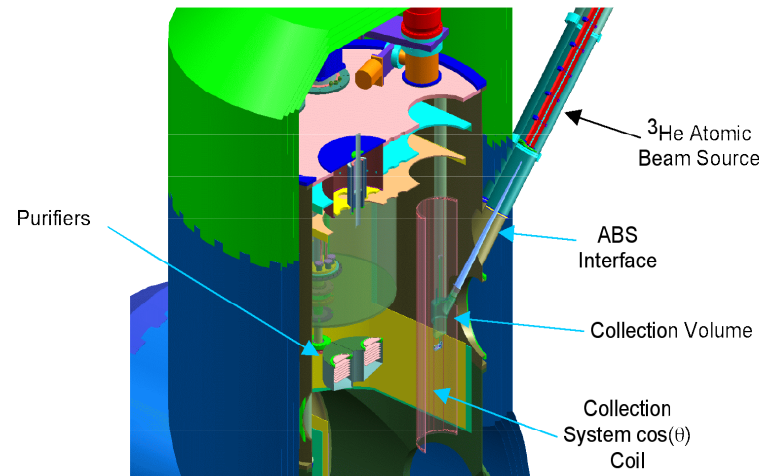
- Simulation to show that the Eddy current heating in 4 K shield is $< 100 \text{ mW}$
- Calculated I^2R and thermal heat load at 4.2 K is $< 500 \text{ mW}$

- Before arrival (cont.):
 - Magnetic shield assembly shown to meet our collaboration requirements:
 - Controlled low temperature test and characterization of the ferromagnetic shield performed.
 - Controlled low temperature test and characterization of the superconducting shield performed, preferably w/ ferromagnetic shield.
 - Internal shield tests, when combined with the results from external μ -metal shield tests, provide a total shielding factor of $> 8 \times 10^4$.



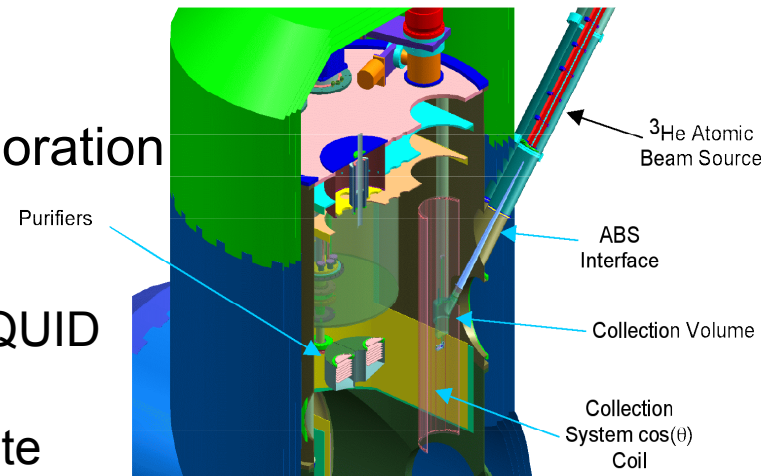
■ Before arrival:

- Design fully incorporated into the cryovessel design and vetted from a cryogenics standpoint (ie. it will fit in and cool down). Implemented with appropriate sensors.
- Assembly shown to meet the CD-4 requirements at 0.5 K:
 - ABS produces $\geq 10^{11}/\text{cm}^3$ of $\geq 70\%$ -polarized ^3He in the collection volume as seen with a SQUID
 - Purifier reduces the ^3He concentration to less than 1 part in 10^{11}
 - ^3He demonstrated to move between volumes with a time constant of 500 s or less
 - Valves working and shown to operate over 500 cycles



■ Before arrival:

- Assembly shown to meet our collaboration requirements at 500 mK:
 - Injection ^3He polarization in the collection volume as seen with a SQUID is $> 98\%$.
 - Valves working and shown to operate reliably over 8×10^4 cycles.
 - ^3He polarization lifetime in the measurement cells is measured to be greater than 20,000 s.
 - Purifier and injection/transport system shown to work at 500 mK in two independent tests.
 - Polarized ^3He from the ABS fills the collection volume and is then transported along a similar impedance to a full size measurement cell. ^3He polarization is measured in both the cell and collection volume.
 - Operation of the purifier demonstrated, including the regeneration of the charcoal adsorption pumps.



To be performed after assembly



- Measurement of the alignment of E/B

- Reminder: the duration and costs are dominated by the length and number of cooldowns.
- Subsystems must be fully vetted before we attempt to assemble them into the main apparatus!
- In working up the CD-2 documentation, make sure you have incorporated the appropriate tests (and costs) into the WBS. The assembly subgroup assumes systems arrive fully tested and are ready to incorporate into the cryovessel. Any assembly jigs, etc. should either ship with the subsystem or be included in the infrastructure subgroup.